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Effect of various potassium and nitrogen rates and splitting methods on potato under sandy soil and arid environmental conditions

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Abstract: Potatoes require high amounts of potassium (K) and nitrogen (N) fertilizers for optimum growth, production and tuber quality. Farmers and farming industries under the arid conditions and sandy soils of Saudi Arabia are applying K and N fertilizers to potatoes without attention to plant requirements. Therefore, five levels of potassium fertilizer were studied on agronomic performance, tuber quality and total yield of potatoes grown on a sandy soil in the arid environment of Central Saudi Arabia. Also, the effect of four levels of nitrogen fertilizer with different splitting methods on vegetative and tuber yields of potato were studied. The field experiments were carried out during 2002 and 2003 autumn seasons at the Experimental Farm of College of Agric. &Vet. Med., Al-Qassim University. Results reveled that increasing potassium sulfate rates resulted in a significant increase ($p \geq 0.05$) in plant height, leaf area, chlorophyll concentration, specific gravity, K concentration and carbohydrate content. Marketable tuber yield was also significantly improved with increasing K rates. Also, the application of 300 kg Nha^{-1} split in three equal doses gave the highest percentage of soil coverage and marketable tuber yield. Under the conditions of this experiment, it is concluded that K and N is needed by potatoes for economic yield. The recommended rate for Al-Qassim and similar regions is 450 kg ha^{-1} potassium sulfate and 300 kg Nha^{-1} split in three equal doses which resulted in the highest potatoes yield.

Key words: *Solanum tuberosum*, potassium sulphate, urea, fertilization, K element, N element, vegetative growth, yield quality, potato production.

تأثير معدلات وطرق إضافة كل من البوتاسيوم والنيتروجين على نمو وإنتاج وجودة البطاطس تحت الظروف القاحلة والأراضي الرملية

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الملخص: تحتاج البطاطس إلي كميات عالية من التسميد النيتروجيني والبوتاسي للحصول على النمو المثالي والإنتاجية وجودة الدرنات. يقوم المزارعون في المناطق الجافة والأراضي الرملية في المملكة العربية السعودية بالتسميد النيتروجيني والبوتاسي للبطاطس بغض النظر عن الاحتياجات الفعلية للنبات. الهدف من هذه الدراسة تقيم تأثير معدلات و طرق إضافة النيتروجين والبوتاسيوم على النمو الخضري والإنتاجي وجودة الدرنات ومحصول البطاطس النامية في الأراضي الرملية في الظروف الجافة للمنطقة الوسطي للمملكة العربية السعودية. أجريت هذه الدراسة في الموسم الخريفي لعامي ٢٠٠٢/٢٠٠١ & ٢٠٠٣/٢٠٠٢ في محطة التجارب الزراعية التابعة لجامعة القصيم باستخدام خمس مستويات من التسميد البوتاسي (تراوحت من الصفر إلى ٦٠٠ كجم كبريتات بوتاسيوم/هكتار) وأيضاً أربع مستويات من السماد النيتروجيني مضافا مره واحدة أو مرتين أو ثلاث مرات. وأوضحت النتائج أن زيادة معدل كبريتات البوتاسيوم أدى إلى زيادة معنوية في طول النبات والمساحة الورقية ونسبة الكلوروفيل وكذا الكثافة النوعية ومحتوى الدرنات من كل من البوتاسيوم والكربوهيدرات. ولقد زاد أيضاً محصول البطاطس القابل للتسويق بزيادة معدل التسميد البوتاسي. كما أن زيادة معدل التسميد النيتروجيني مضافاً على ثلاث مرات يؤدي إلى

زيادة مساحة التغطية وبالتالي محصول البطاطس القابل للتسويق. لذلك يمكن التوصية بإضافة ٤٥٠ كجم كبريتات بوتاسيوم للهكتار و ٣٠٠ كجم نيتروجين للهكتار مضافاً على ثلاث مرات للحصول على أعلى محصول من البطاطس وذلك تحت ظروف المناطق الجافة ذات الترب الرملية القوام.

كلمات مفتاحية: كبريتات بوتاسيوم، يوريا، تسميد، عنصر النيتروجين، عنصر البوتاسيوم، النمو الخضري، نوعية المحصول، إنتاج البطاطس.

Introduction

The potato, *Solanum tuberosum* L., is the fourth most important world crop, after rice, wheat and maize (Spooner and Bamberg, 1994). It is a major source of inexpensive energy. It contains high levels of carbohydrates and significant amounts of vitamins B and C and other minerals. Moreover, potato is used in many industries, such as French fries, chips, starch and alcohol production (Abdel-Aal, et al., 1977).

In Saudi Arabia, potato is one of the most important crops, and Al-Qassim region alone accounts for about half of the annual potato production in the country (Zaag, 1991). It is mainly produced on coarse textured calcareous soils in arid land, and under center pivot irrigation systems. Average yields vary between 20 and 40 t/ha (Abdelgadir et al., 2003). The crop is judiciously fertilized with N, P and K and other elements based mainly on practical experience as there is a lack of recommendations based on correlation/calibration research. Potato plants require much more potassium than many other vegetable crops. Although most soils in Saudi Arabia are rich in K. Potassium fertilizer should be applied to sustain high yields (Zaag, 1991). An adequate supply of potassium strengthens stems to prevent lodging, increases yield and improves tuber quality (Beringer 1987; Ibrahim et al., 1987 and Omran et al., 1991). It also allows the crops to adapt to environmental stress, and promotes plant tolerance to insect infection and resistance to fungal disease. Moreover, k fertilizer reduced frost injury and enzymatic browning. It increased starch, total sugar, sugar, reducing sugar, protein and ascorbic acid content of tubers (Rajanne et al., 1987 and Sahota et al., 1988).

From early studies, Terman (1950) pointed out that there was a consistent decrease in the starch content of potato tubers with increase in the rate of K_2O application. In a similar study Hart and Smith (1966) reported that dry matter of potatoes decreased with increasing K level. Excess K fertilizer was reported to reduce dry matter or specific gravity (Schippers, 1968; McDole, 1978 and Westermann et al., 1994a,b).

There is a general belief among farming communities in Saudi Arabia that a higher and a better quality yield of potato crop is always obtained when K is added in high quantities. Although the potato crop requires a heavy input of K for high yields (Errebhi et al., 1998), adequate levels should be established for economic yields and sustainable productivity. It is well documented that K affects potato quality and yield. Insufficient K results in reduced potato yield and smaller-sized tubers (McDole, 1978; Satyanarayana and Arora, 1985). Compared with the low K rate, the higher k rate increased the yield of medium (28-60mm) and over-sized (>60mm) tubers by approximately 15 and 40%, respectively (Tawfik, 2001). Other workers found that a significant tuber yield responses to K fertilization

(Westermann et al., 1994a and Panique et al., 1997). Under the arid conditions of Wadi Ad Dawassir (latitude 20-21 N, longitude 45-46 E), Saudi Arabia, Abdelgadir et al. (2003) found that application of 215 kg K_2O ha^{-1} was sufficient to produce an economic yield and high quality of potatoes. On the other hand, farming industries (Nadec, 2003) are applying rates higher than those reported by Abdelgader et al. (2003).

It is widely accepted that nitrogen is the most limiting nutritional factor to crop production in arid, semiarid, and desert lands. Thus, addition of N-fertilizer to soils has become a mandatory agricultural practice in arid regions. The main source of N in Saudi Arabia is urea (46%N); urea is the most popular straight, solid N fertilizer that is used for potato production worldwide (UNIDO and IFDC, 1998). The potato crop particularly, requires high amounts of N for optimum yields (Errebhi et al., 1998). However, the use of N fertilizers is often held responsible for gaseous N emissions into the atmosphere (Debreczeni and Berecz, 1998; Goos and de Padua Cruz, 1999; Skiba et al., 1997) and underground water pollution (Viets, 1975; Vitosh, 1986; Adetunji, 1994; Errebhi et al., 1998). Therefore, in recent years, research and practice in arid zones of Saudi Arabia has focused on the splitting of potato N requirement into small doses to minimize gaseous losses. Under the arid conditions of Wadi Ad Dawassir, Abdelgadir et al. (2003) reported that N level of 270 kg N ha^{-1} was sufficient to produce economic yields and high quality potatoes. The objectives of this study were to: (1) evaluate the effect of different rates of potassium sulphate, K_2SO_4, (50% K_2O), on agronomic performance, tuber quality and total yield of potatoes, and (2) study the effect of different rates of nitrogen fertilizer with no, two and three splits during the growing season on vegetative and tuber yield of potatoes grown in a sandy soil under arid environmental conditions.

Materials and Methods

The present study was conducted during the seasons of 2002 and 2003 at the Experimental farm of the College of Agriculture and Veterinary Medicine, King Saud University, Al-Qassium region (latitude 26-27 N, longitude 44-45 E, altitude 725 m above sea level), Kingdom of Saudi Arabia. The site of the experiment is typical arid environment with maximum and minimum mean temperature of 29°C and 16.0°C, respectively. The maximum and minimum mean relative humidity are 43.3 and 18.3%, respectively. Soil samples were collected prior to planting at 0-20 cm depth and their properties were given in Table (1). Experimental area was divided into 32 plots (15 for K and 27 for N) separated by 1 m as border. Plot size was 4 x 3 m. Plots were arranged in a randomized complete block design, with 3 replications. All plots received basic application of 250 kg P_2O_5 ha^{-1} using diammonium phosphate (46% P_2O_5), applied at once before planting. Planting date was 18 September 2002 and 2003.

K Treatments

Five treatments (0, 150, 300, 450, and 600 kg K_2SO_4 ha^{-1}) were studied. Pre-sprouted tubers of cultivar Ajax were planted in rows (75 cm apart) at 30 cm spacing between plants. All plots received 300 kg N ha^{-1} using urea (46%N).

During the growing season, plant height, leaf area, chlorophyll and carbohydrate content were determined. Harvesting was carried out on 10 January 2002. Potato tubers were then graded visually into marketable (>3.5 cm in diameter) and cull (<3.5 cm, bruised, green or sprouted tubers). Marketable and total tuber yield were determined by weight, and only marketable tuber data is reported in this paper. Potato tuber samples were then collected from all treatments for dry matter, specific gravity, carbohydrates percent and K content determinations. Specific gravity was determined by the hydrometer method on a 5.0-kg sub-sample of the marketable potatoes (Edgar, 1951).

N Treatments

The source of N was urea (46%N), and N levels were 0, 150, 300, and 450 kg N ha^{-1}, arranged into the following nine treatments:

- Control (no nitrogen application).
- Application of N at the rate of 150 kg N ha^{-1} at planting time.
- Application of N at the rate of 150 kg ha^{-1}, split into two equal doses: planting date and 45 days after planting.
- Application of N at the rate of 150 kg ha^{-1}, split into three equal doses: 0, 45, and 60 days after planting.
- Application of N at the rate of 300 kg N ha^{-1} at planting time.
- Application of N at the rate of 300 kg ha^{-1}, split into two equal doses: planting date and 45 days after planting.
- Application of N at the rate of 300 kg ha^{-1}, split into three equal doses: 0, 45, and 60 days after planting.
- Application of N at the rate of 450 kg ha^{-1} at planting time.
- Application of N at the rate of 450 kg ha^{-1}, split into two equal doses: planting date and 45 days after planting.
- Application of N at the rate of 450 kg ha^{-1}, split into three equal doses: 0, 45, and 60 days after planting.

All plots received 300 kg K_2O ha^{-1} using K_2SO_4 (50% K_2O). Pre-sprouted tubers of cultivar Ajax were planted in rows (75 cm apart) at 30 cm spacing between plants. The growing seasons were 106 and 104 days, for the 2002 and 2003 experiments, respectively. Irrigation water samples were also collected and analyzed for EC and pH (Table 1).

Table 1. Physical and chemical proporties of soil and water used for the study.

Property	Soil	Water
Sand (%)	96.3	-
Silt (%)	1.8	-
Clay (%)	1.9	-
Texture	sandy	-
pH[1]	8.4	7.1
EC (mS/cm)	-	1.5
Nutrient (mg/kg)[2]		
Total N	15	-
P	16.5	-
K	36	-

[1] pH was measured in the extract of saturated soil paste
[2] P was extracted using Olsen method; K by 1 N NH_4OAc, pH 7

During the growing season, percent soil coverage and percent tuber dry matter were determined. At the end of each season, harvesting was carried out after growth sensed and complete plants die back. Potato tubers were then graded visually into marketable (>3.5 cm in diameter) and cull (<3.5 cm, bruised, green or sprouted tubers). Marketable and total tuber yield were determined by weight, and only marketable tuber data is reported in this paper.

Statistical analysis was performed on all data using analysis of variance and for treatments comparison; least significant difference at 0.05 probability was used.

Results and Discussion

Effect of different rates of potassium application

Plant Growth Parameters: Plant height was significantly affected by K increasing rate. The highest plant was reached when 600 kg K_2SO_4 ha^{-1} were applied (Table 2). Leaf area ranged from 1127.66 cm^2 per plant at the control plants to 2603.33 cm^2 per plant with application of 600 kg ha^{-1} K_2SO_4. Highest leaf area was obtained with 600 kg K_2SO_4 ha^{-1}. The number of stems per plant, however, was not affected by K rate.

Table 2. Effect of different levels of potassium sulfate on agronomic performance of potato plant

Treatment (kg K_2SO_4ha^{-1})	Plant height (cm)	Leaf area (cm^{2}plant^{-1})	Number of stems (per plant)	Chlorophyll (%)
0	28.0	1127.7	4.0	25.0
150	28.7	1502.7	4.3	27.7
300	39.3	1797.0	3.7	31.0
450	46.3	2504.0	4.7	40.3
600	47.3	2603.3	4.3	43.0
LSD (0.005)	5.5	159.4	NS	4.5

Table 3. Effect of different levels of potassium sulfate on tuber specific gravity, carbohydrates, potassium concentration and marketable yield.

Treatment (kg K_2SO_4ha^{-1})	Specific gravity	Carbohydrates (%)	K (%)	Marketable tuber yield (Ton ha^{-1})
0	1.067	36.7	1.08	17.91
150	1.069	39.7	1.17	21.53
300	1.069	42.7	1.71	28.66
450	1.084	50.7	2.09	31.90
600	1.086	51.33	2.12	31.96
LSD (0.05)	0.003	1.65	0.21	2.43

Tuber Yield and Quality Parameters

Tuber potassium content increased significantly with K rates to reach a statistical maximum of 2.09 % at K rate of 450 kg K_2SO_4 ha^{-1} (Table 3). Carbohydrate percent was increased significantly with increasing K rates. The highest level was reached with application of 450 kg K_2SO_4 ha^{-1}.

Specific gravity was also affected by increasing K rates. These findings are in accordance with those reported by Tawfik (2001) who found that the higher k rate increased the yield of medium (28-60 mm) and over-size (>60mm) tubers by approximately 15 and 40%, respectively, compared with the low potassium rate. In addition, Rajanna et al. (1987) found that potassium fertilizer increased starch, total sugar and reducing sugar. On the other hand, our results did not agree with those of Davenport and Bentley (2001) and Abdelgadir et al. (2003) who found that specific gravity did not respond to K application.

Marketable tuber yield increased significantly ($p < 0.05$) with increasing K rates up to 450 kg K_2SO_4 ha^{-1}. Higher K rates did not improve yield. These results agree with earlier reports by James et al. (1968), McDole (1978), Lal and Singh (1983), Rhue et al. (1986) and Chapman et al. (1992). Marketable tuber yield for K fertilized plots ranged from 21.53 to 31.96 tons ha^{-1}. These yield ranges are within the 20 to 40 kg ha^{-1} yields for Saudi Arabia; they are also comparable to yield data reported by Abdelgadir et al. (2003) for Wadi Ad Dawassir (latitude 20-21 N, longitude 45-46 E), Saudi Arabia.

Effect of different levels and splits of nitrogen fertilizer

Soil Coverage: For both seasons, and within each N level, the splitting of N doses significantly ($p \geq 0.05$) increased leaf soil coverage (Table 4). The highest percentage of leaf soil coverage (72.48 and 67.96 %) was obtained at the application of 300 kg N $ha^{-1}$with split into three equal doses applied at 0, 45 and 60 days after planting during the growing seasons 2002 and 2003, respectively.

Tuber Production: There is no clear and definite effect of N rate and splitting on tuber dry matter. Application of N to potatoes grown in a sandy soil under arid environmental condition significantly increased marketable tuber yield (Table 4). In both growing seasons, and without splitting the dose, increasing N rate resulted in a statistical tuber yield increase until the rate of 300 kg N ha^{-1}. Splitting 150 kg N ha-1 in three equal doses applied at 0, 45 and 60 days after planting gave the highest potato tuber yield. Similar results were found for the 300 and 450 kg N ha^{-1}. However, the highest potato tuber yield was obtained at the rate of 300 kg N ha^{-1} with split into three equal doses applied at 0, 45 and 60 days after planting for the both seasons. It should noted that the application of 300 kg N ha^{-1} with three split, also, gave the highest percentage of soil coverage. Therefore, it is clear that potato production came as a result of plant vegetative growth development. Same findings were reported by Al-Moshileh and Motawei (2001) and by Al-Moshileh et al. (2003). Also, data of the present study agree with previous reports of Errebhi et al. (1998) and Abdelgadir et al. (2003). However, Riley (2000) working on N timing effects on potatoes in Norway reported that there were no benefit from splitting the N application.

We believe that splitting N for potatoes grown in the sandy soils of arid Central Saudi Arabia is necessary for two main reasons; soils are calcareous, and N can easily be lost by volatilization if applied at once or even twice during the growing season; in addition, the potato crop is being irrigated every three days and, in hot months, daily, a practice that makes the potential for leaching N fertilizer below the rooting zone very high. In these two experiments, it is found that splitting N up to three times gave the best results. It is possible that splitting N to even higher number of times with smaller doses leads smaller N losses, and therefore, higher tuber yield.

Table 4. Effect of different levels and splits of nitrogen on percent soil coverage, percent tuber dry matter and marketable tuber yield

Treatment	Soil coverage (%)		Tuber dry matter (%)		Marketable tuber yield (ton ha^{-1})	
	2002	2003	2002	2003	2002	2003
Control	34.5	32.0	17.0	14.2	18.5	17.2
150 (once)	45.2	45.1	20.2	16.8	27.8	22.6
150 –2 splits	60.4	56.6	18.7	16.4	29.1	24.8
150 –3 splits	71.5	66.9	18.3	15.7	33.6	28.9
300 (once)	47.4	44.5	19.4	18.3	30.8	28.3
300 –2 splits	52.7	49.3	19.8	18.2	25.3	24.9
300 –3 splits	72.5	68.0	17.5	16.4	34.5	39.9
450 (once)	39.4	40.6	19.5	18.9	20.6	17.7
450 –2 splits	53.5	46.9	18.7	17.1	25.2	24.3
450 –3 splits	55.9	58.4	18.8	17.6	26.2	23.3
LSD (0.05)	3.35	2.84	1.20	2.02	1.35	2.64

Conclusion and Recommendation

Both plant nutritional status and tuber quality parameters responded positively to increasing K application rates. Marketable tuber yield was significantly affected by K fertilizer levels. Highest yield and other quality parameters were achieved when a rate of 450 kg K_2SO_4 ha^{-1} was used. We recommend that, for Qassim and similar regions in Saudi Arabia, farmers apply potassium sulfate at the rate of 450 kg K_2SO_4 ha^{-1} for optimum yield. Application of N improved potato tuber yield; increasing N rates to 300 kg N ha^{-1} increased tuber yield. However, higher N rate of 450 kg N ha^{-1} resulted a drop in tuber yield. Splitting N rates into three doses applied equally at 0, 45, and 60 days after planting date improved yield. Results from these two experiments indicated that splitting 300 kg N ha^{-1} into three equal doses applied at 0, 45, and 60 days after planting date, gave the highest potato tuber yield. More researchers are needed to investigate the benefits of further splitting of N fertilizer for potatoes grown in the sandy soils under arid conditions of Central Saudi Arabia

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